Transverse Momentum Spectra of Identified Hadrons in $\sqrt{s}$ = 130 GeV Au-Au Collisions

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for the PHENIX Collaboration

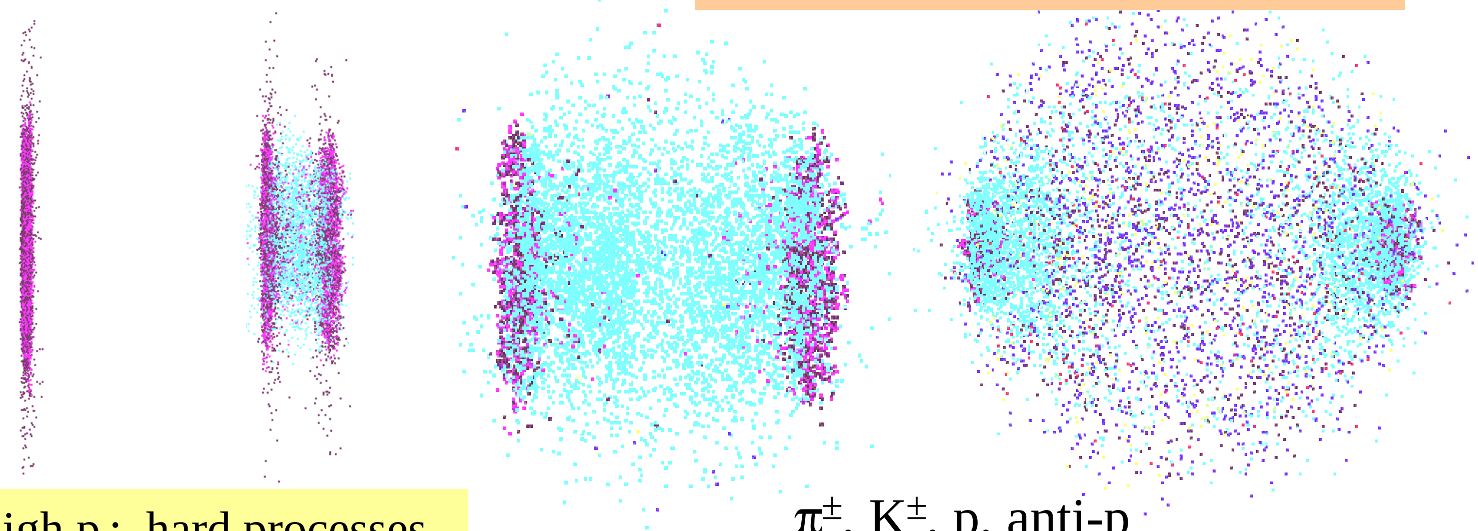
Outline of Topics

- Motivation
- Identifying $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ in PHENIX
- Single Particle P_t spectra
- Radial flow
  - –hydrodynamics-based parameterization
- Discussion and conclusion

Motivation

RHIC: E_{cm} = 130 GeV
Au on Au collisions

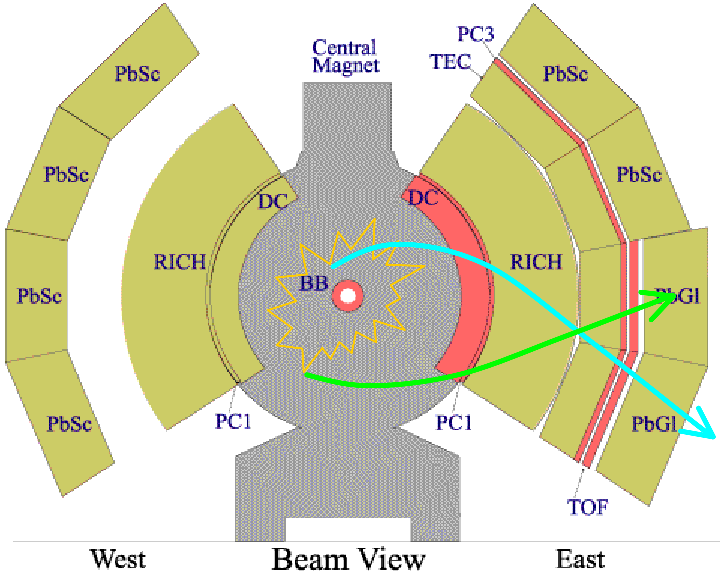
low p_t: soft processes
multiple hadronic rescattering
hydrodynamic behavior



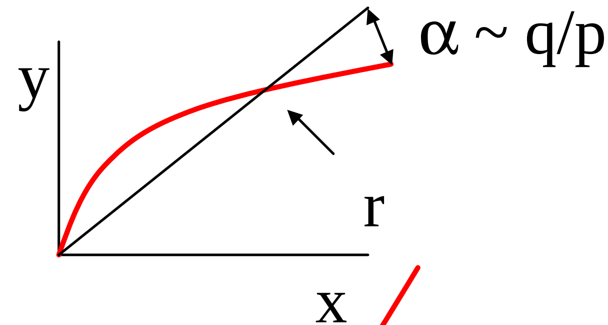
high p_t: hard processes
hard scattering, jets
pQCD

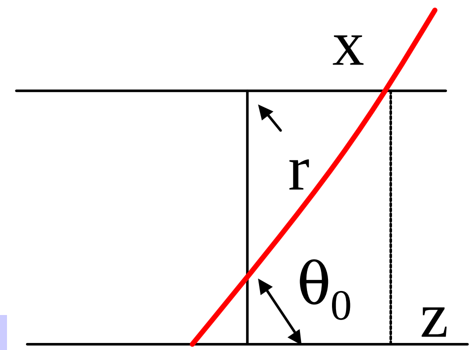
$\pi^{\pm}$, $K^{\pm}$, p, anti-p
carry most of energy
collectively flow at β_t
decouple at T_{fo}

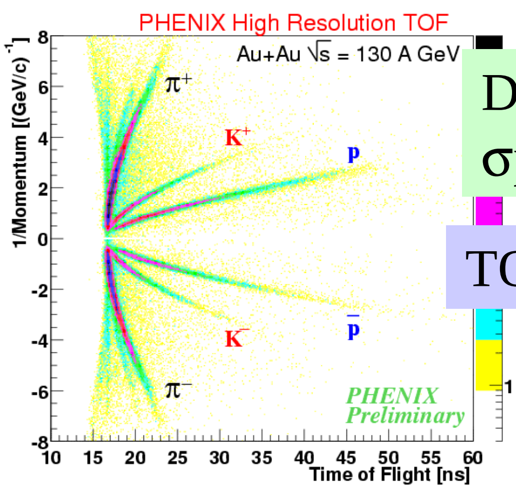
Detecting $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ in PHENIX



DC
main bend plane







DC resolution
$\sigma p/p \sim 1\% \oplus 3.5\%\ p$

TOF resolution 115 ps

$p_t = p \sin(\theta_0)$

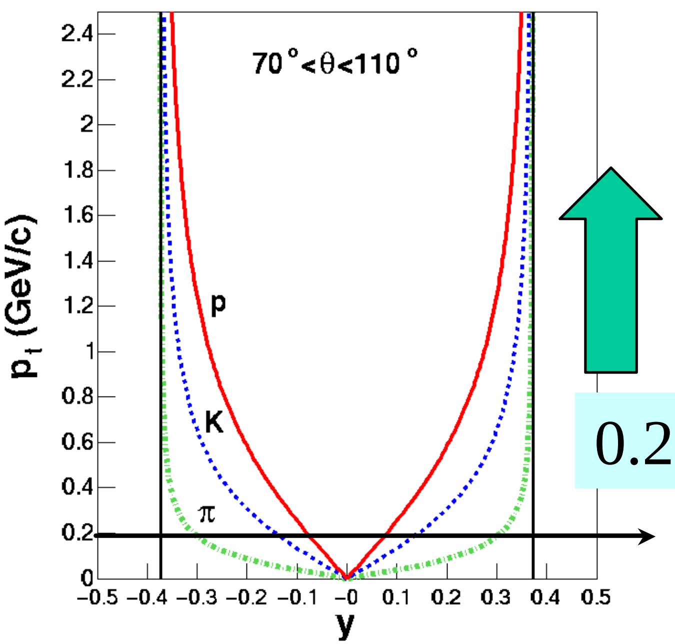
PC1 and Event vertex
polar angle

Corrections to the Raw Spectra

Used MC single particles and track embedding to correct for

- Tracking inefficiencies and momentum resolution
- Geometrical acceptance
- Decays in flight (π's and K's)

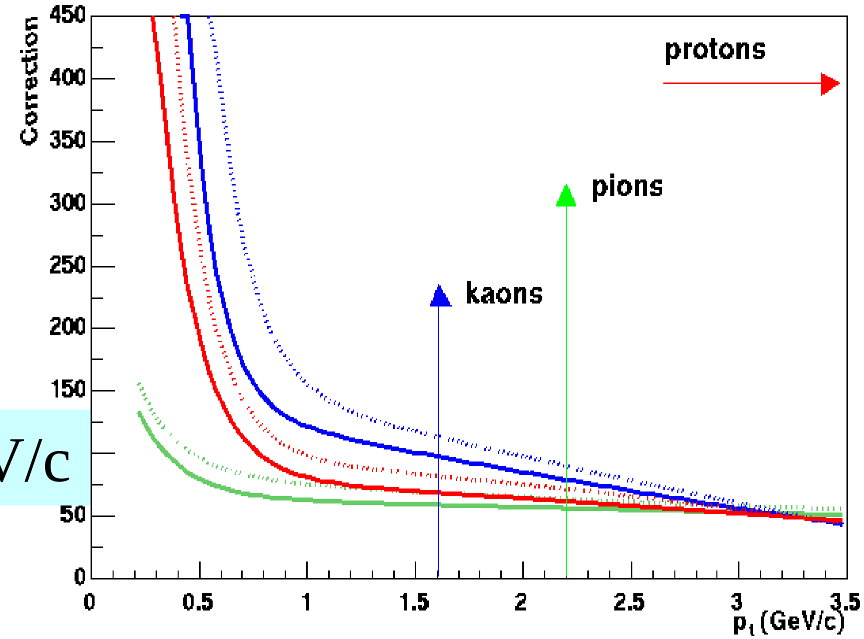
Particle Acceptance



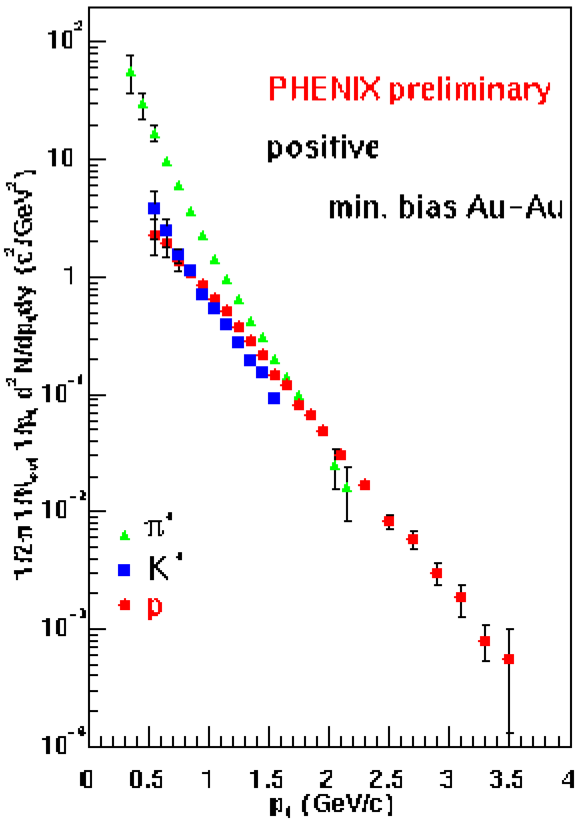
0.2 GeV/c

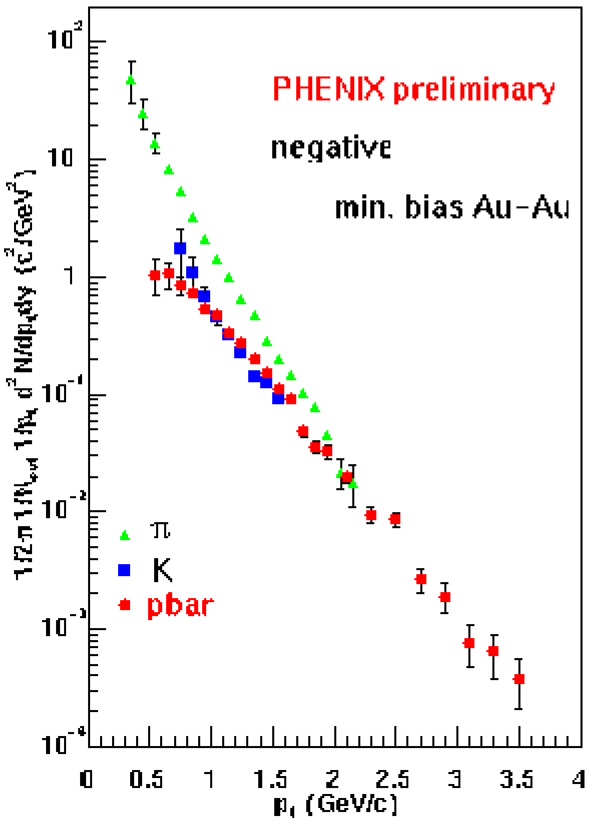
-0.35 < η < 0.35

Correction is p and PID dependent

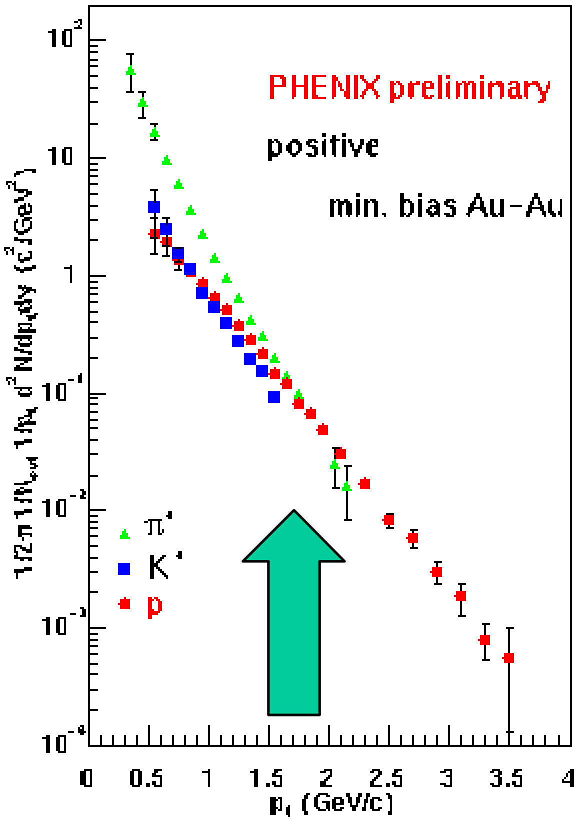


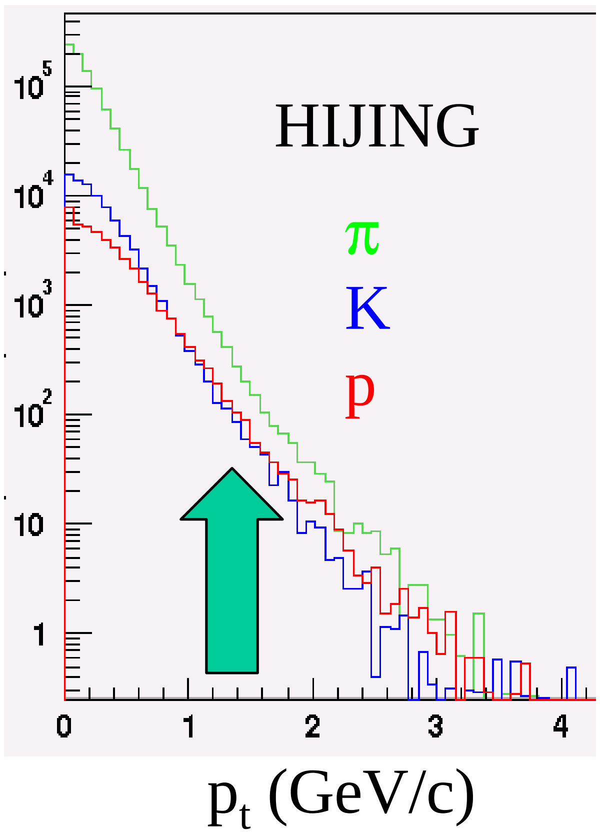
p_t Spectra of Identified Hadrons





Protons Cross the Pions?

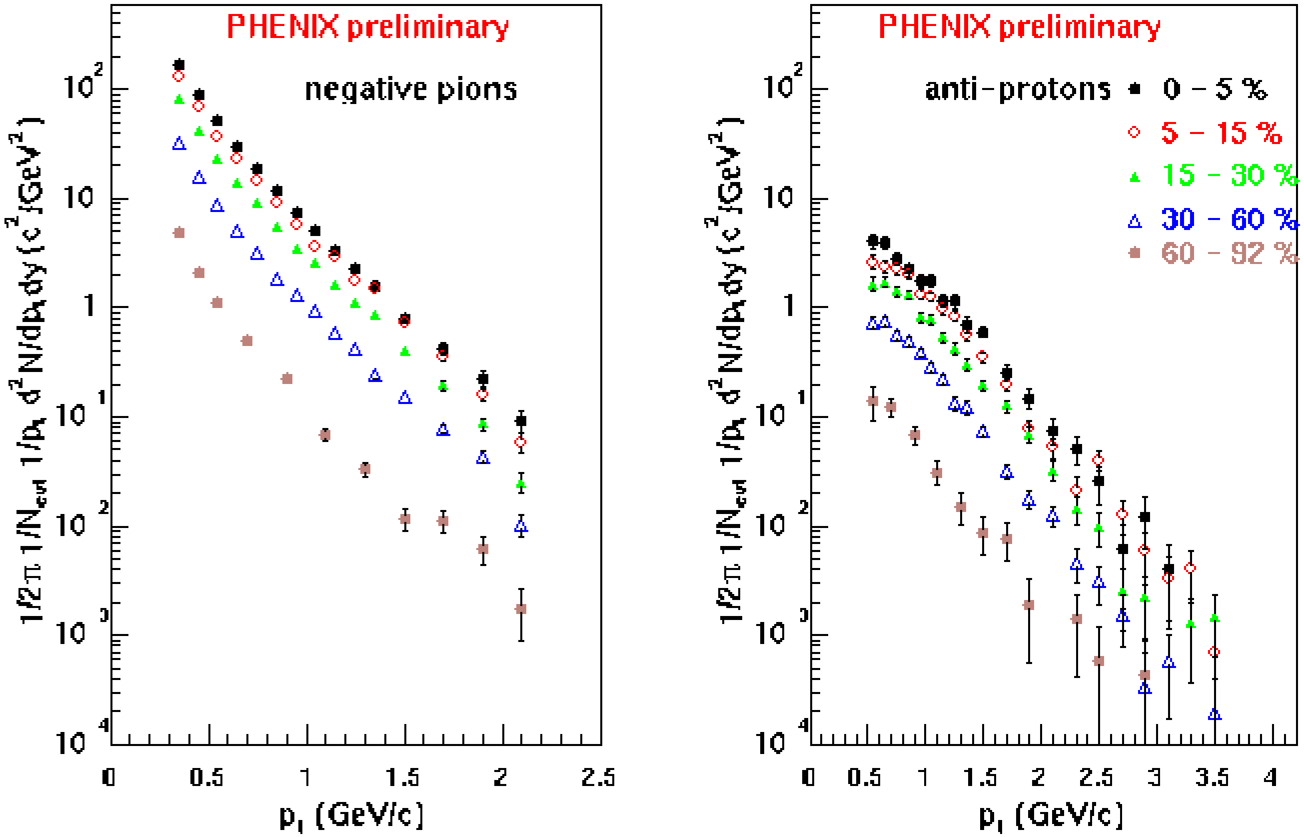




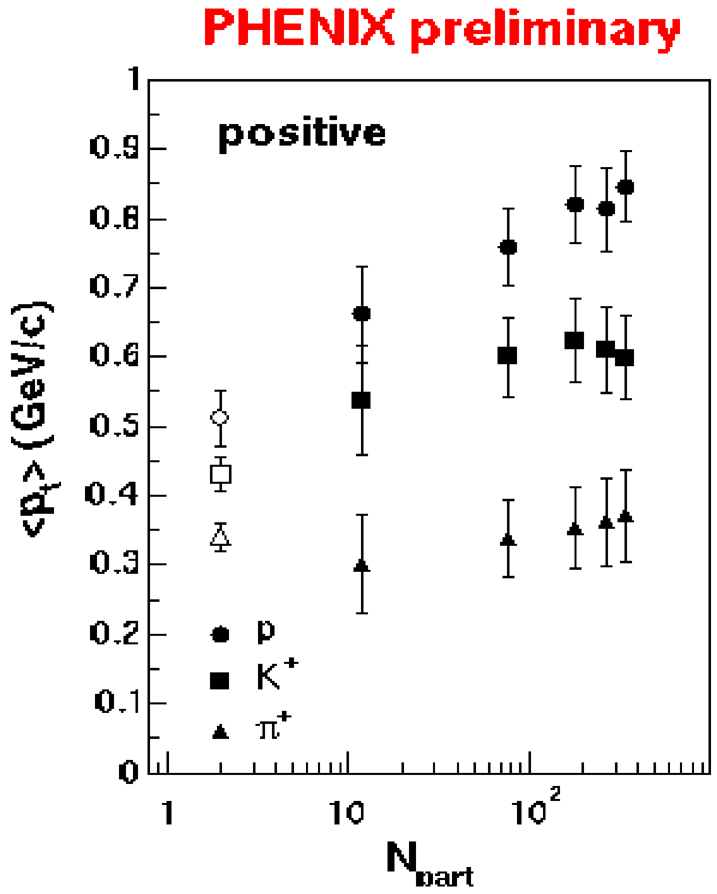
p crosses π

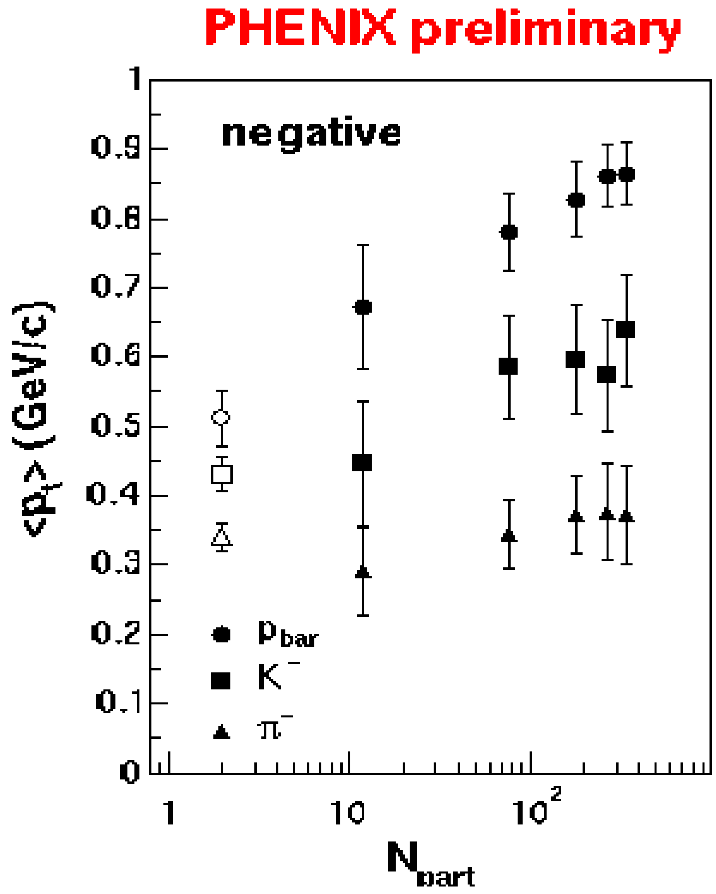
p crosses K

Centrality selected p_t spectra. . .



$<p_t>$ Across Participant Number



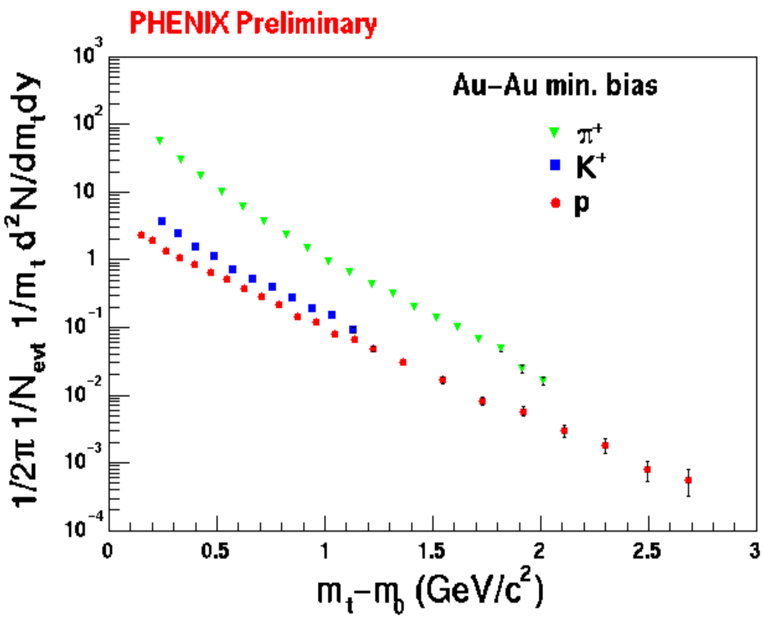


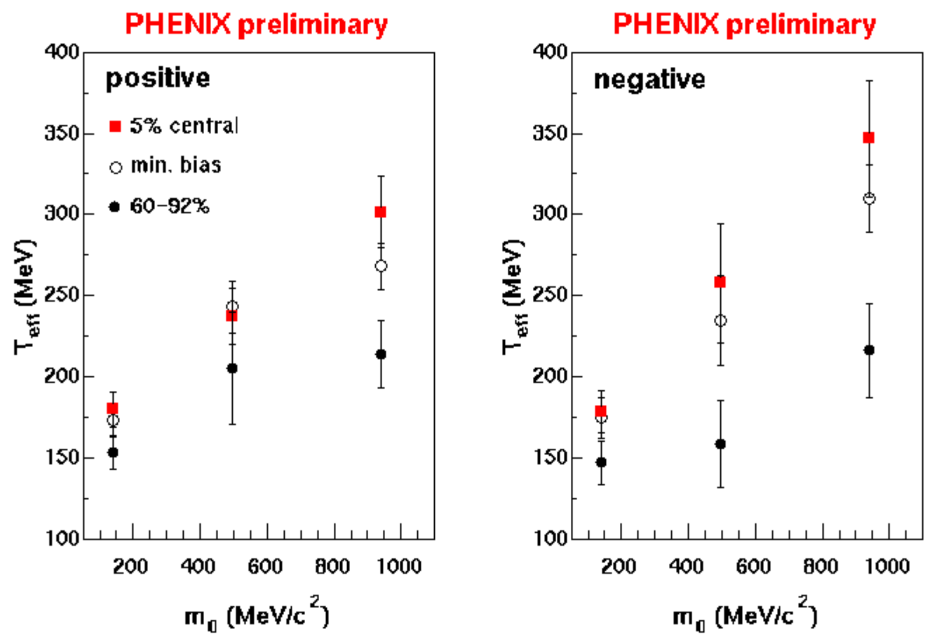
Identified particle m_t-m_0 Spectra

In the range $m_t - m_0 < 1$ GeV, fit and extract the inverse slope T_{eff}

$$\frac{1}{m_t}\frac{dN}{dm_t} \propto e^{-\frac{m_t}{T_{eff}}}$$

$$\frac{1}{p_t}\frac{dN}{dp_t} = \frac{1}{m_t}\frac{dN}{dm_t} \qquad m_t = \sqrt{m_0^2 + p_t^2}$$

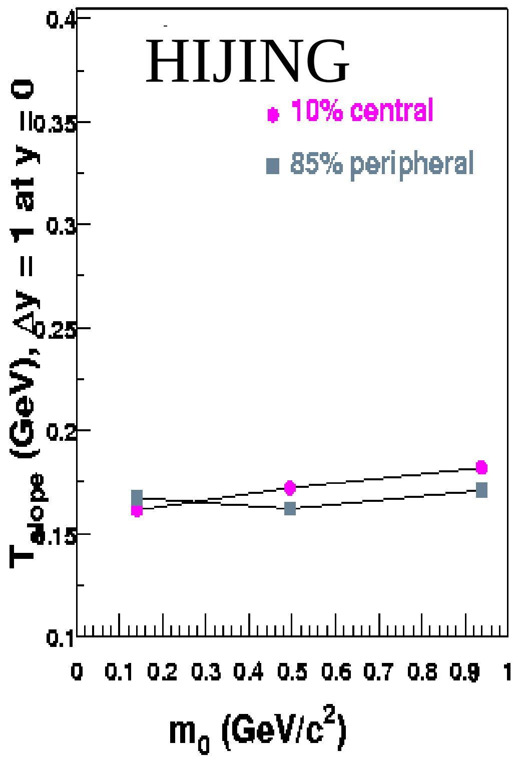


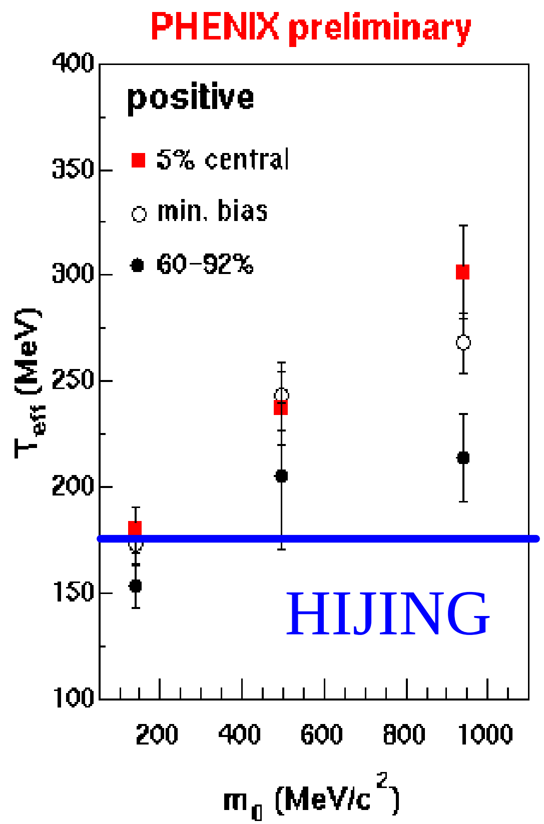


If static thermal source, then spectra are parallel

Effective Temperature and HIJING

No radial flow in HIJING



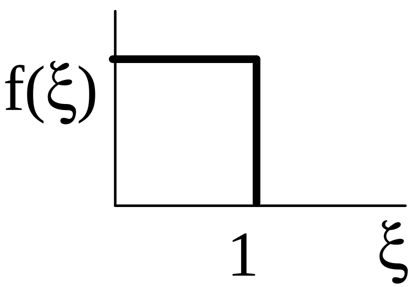


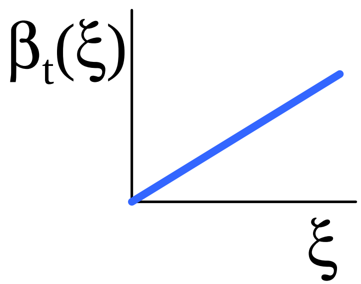
To measure the expansion parameters, use hydrodynamics-based parameterization. . .

Hydrodynamics-based parameterization

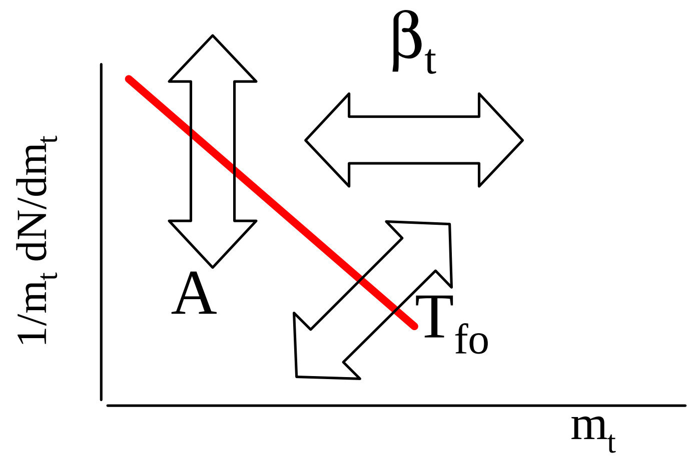
$$1/m_t \, dN/dm_t = A \int f(\xi)\, \xi \, d\xi \; m_T \; K_1(m_T / T_{fo} \cosh \rho)\, I_0(p_T / T_{fo} \sinh \rho)$$

integration variable
$\xi \leftrightarrow$ radius r
$= r/R$
definite integral from 0 to 1
particle density distribution $f(\xi) \sim$ const





linear velocity profile $\beta_t(\xi) = \beta_t \xi$
surf. velocity β_t
ave. velocity $\langle \beta_t \rangle = 2/3\, \beta_t$
boost $\rho(\xi) = \mathrm{atanh}(\beta_t(\xi))$



parameters
normalization A
freeze-out temperature T_{fo}
surface velocity β_t

minimize contributions from hard processes fit m_t-m_0<1 GeV

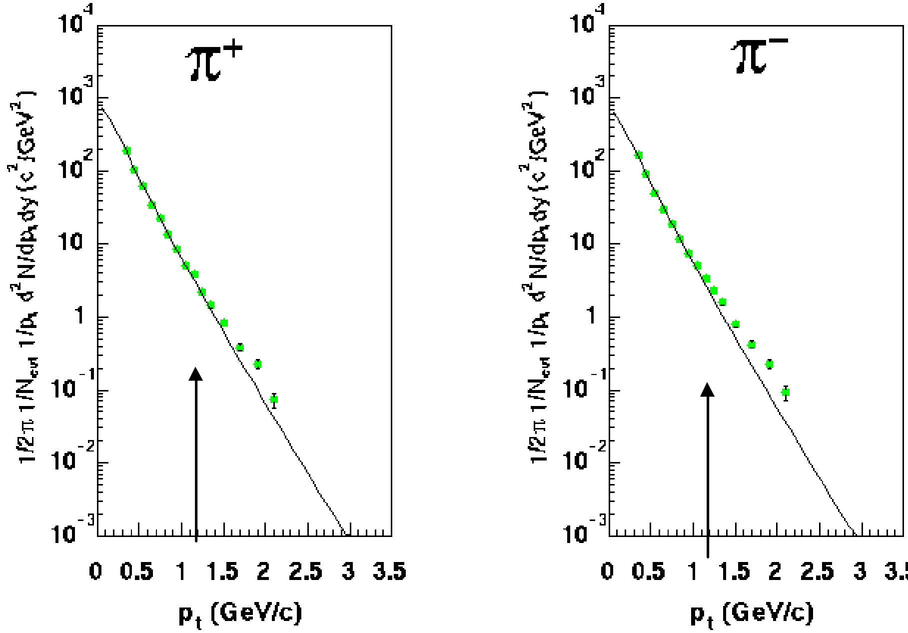
5% central data

$T_{fo} \sim 104 \pm 21$ MeV
$\beta_t \sim 0.7 \mp 0.1$
$< \beta_t > \sim 0.5 \mp 0.1$

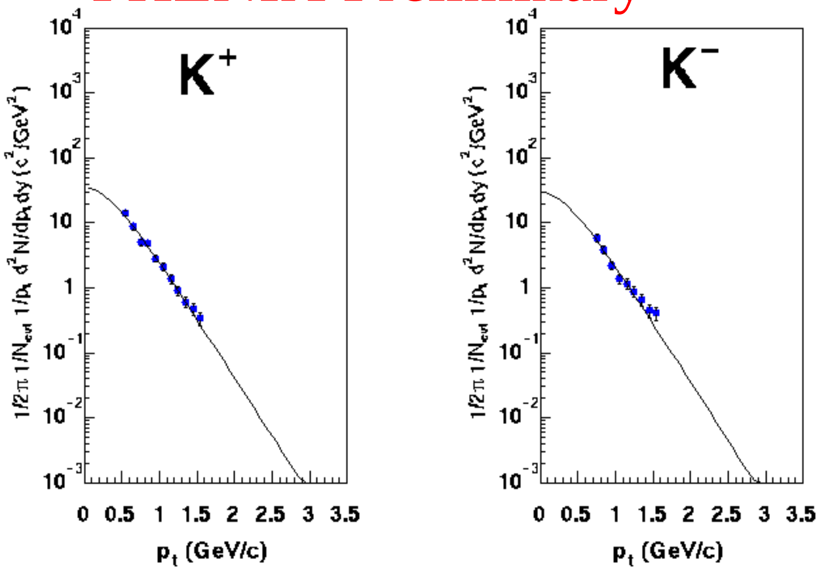
Systematic errors estimated
~8% in T_{fo} ~5% in β_t

Arrows indicate upper p_t in fit

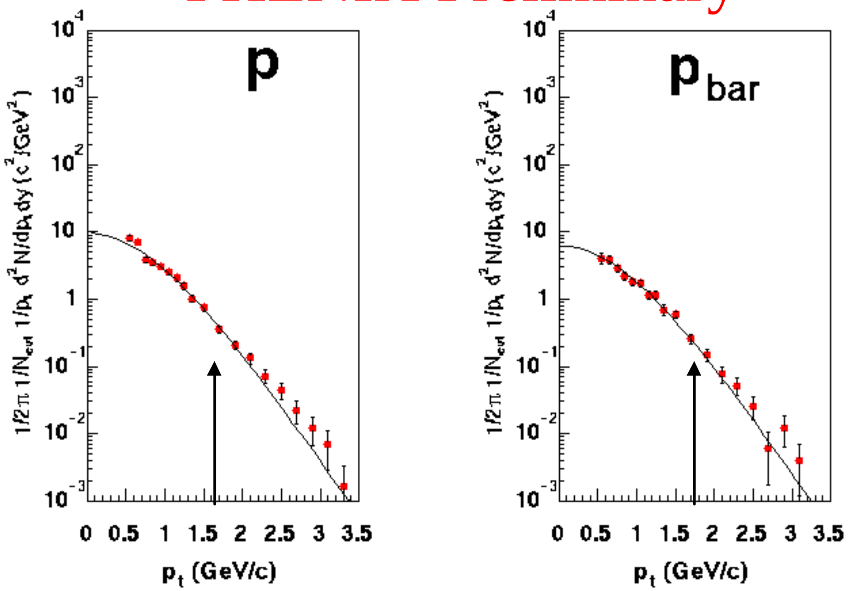
PHENIX Preliminary



PHENIX Preliminary

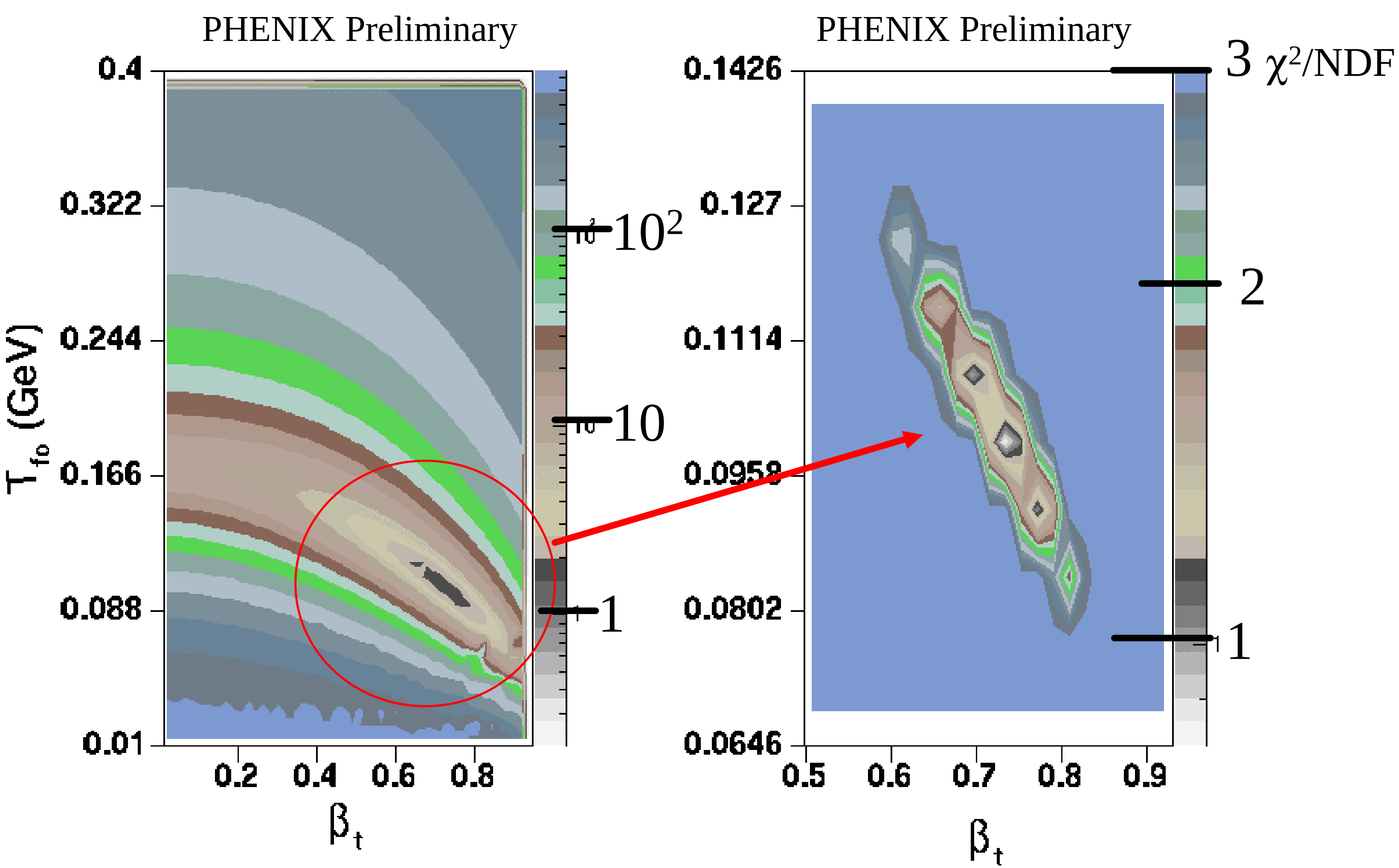


PHENIX Preliminary

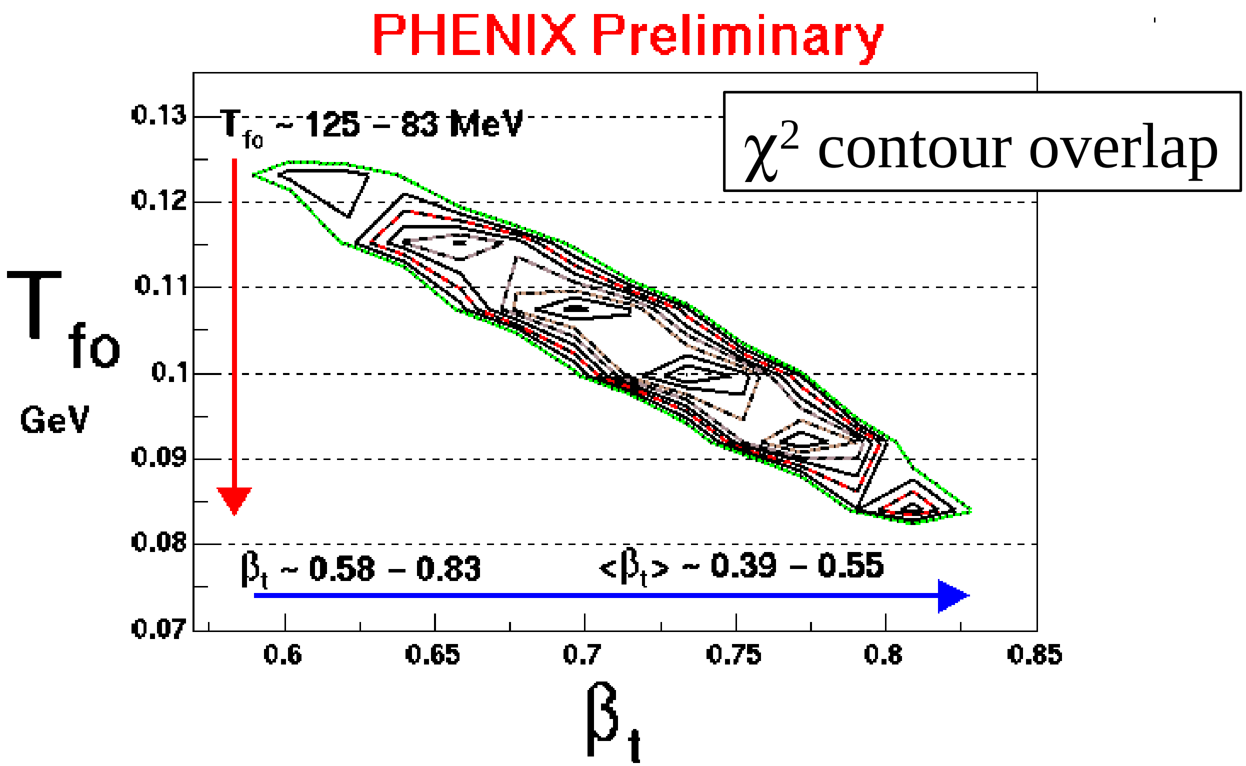


Parameter Space: χ^2 Contours of π-K-p

5% central



Overlap Region in Parameter Space



T_{fo} ~ 125 - 83 MeV ~ 104 MeV
β_t ~ 0.6 - 0.8 ~ 0.7
$<\beta_t>$ ~ 0.4 - 0.6 ~ 0.5

CERN Pb-Pb NA49:
T ~ 132 - 108 MeV ~ 120 MeV
β_t ~ 0.43 - 0.67 ~ 0.55

Systematic errors estimated ~8% T_{fo} ~5% β_t

The H2H Model Comparison (Hydro 2 Hadrons)
D. Teaney, E. Shuryak, et. al.

flowing hadronic fluid AND particle cascade

uses Hydrodynamics + Relativistic Quantum Molecular Dynamics (RQMD) cascade

more constrained → predictive power

no scaling of nucleons to match data

$\varepsilon_0 \sim 16.75$ GeV/fm^3 $\tau_0 \sim 1.0$ fm/c

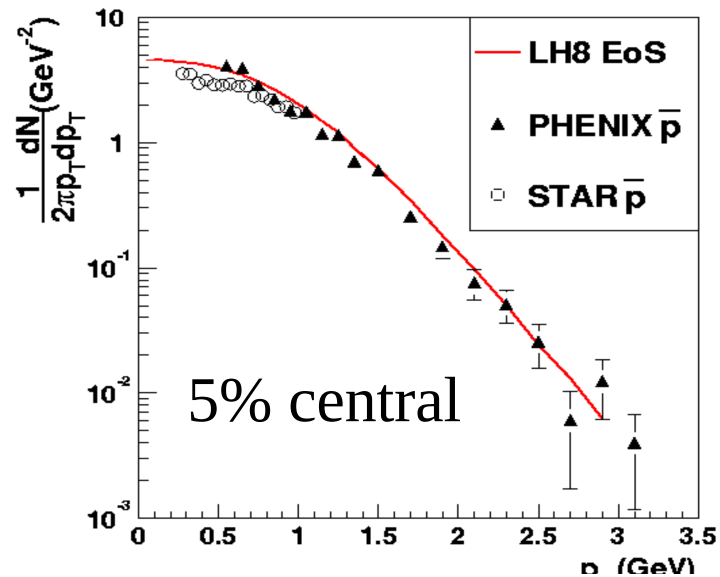
$\bar{p}/p \sim 0.5$

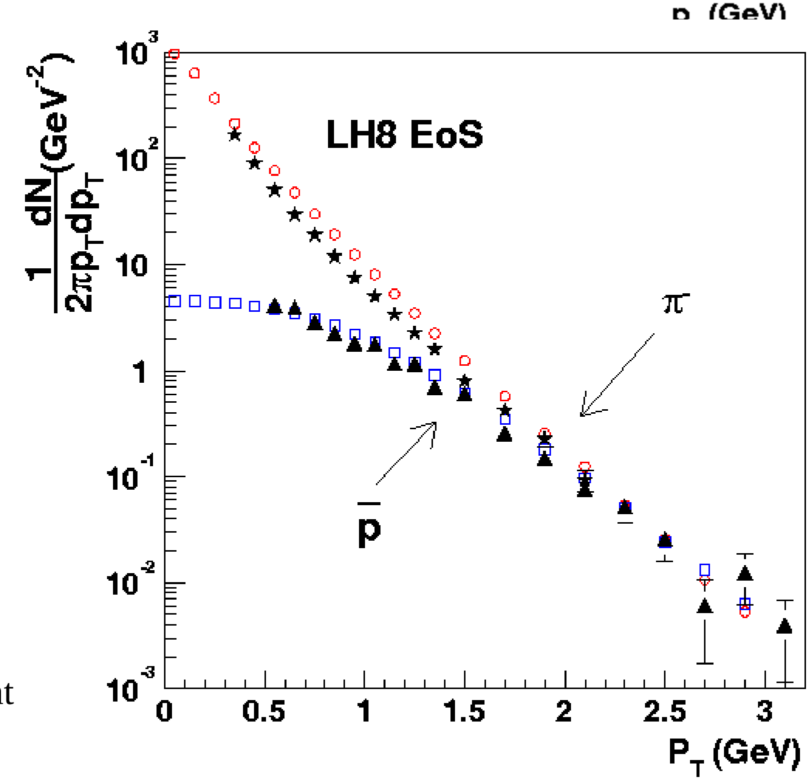
$<\varepsilon_0> \sim 10.95$ GeV/fm^3

π, K $T_{fo} \sim 135$ MeV $<\beta_t> \sim 0.55$

nucleons ~ 120 MeV $<\beta_t> \sim 0.6$

NOTE: includes weak decays





Conclusions

- Fully normalized, centrality selected $\pi^{\pm}$, $K^{\pm}$, p/p_{bar} spectra in 130 GeV Au-Au collisions are measured in PHENIX (Summer 2000 runs)

  significant p and p_{bar} contribution to hadron spectra starting at ~ 2 GeV/c

  STAR and PHENIX p_{bar} consistent
- Both T_{eff} and $<p_t>$ depend on N_{part}. T_{eff} depends on m_0 for 5% central and minimum bias events. There seems to be less of a dependence in the 60 - 92% centrality.
- The data suggest sizeable radial flow at RHIC

  A simple model that assumes hydrodynamic behavior is fit simultaneously to the 5% central data.

  Good χ^2 fits for a finite range of anti-correlated parameters

  T_{fo} ~ 125 - 83 MeV (~ 8% syst.) b_t **~ 0.6 - 0.8 (~ 5% syst.)**

  $< b_t >$ **~ 0.4 - 0.6**

  - In comparison to NA49:

    T_{fo} ~ 132 - 108 MeV β_t ~ 0.43 - 0.67
  - H2H model (D. Teaney, E. Shuryak, et. al)

    π, K: T_{fo} ~ 135 MeV $<\beta_t>$~ 0.55

    nucleons: T_{fo} ~ 120 MeV $<\beta_t>$~ 0.6
- Reduce 20% systematic uncertainty in overall normalization.

The mass-squared width: how particle identification is done.

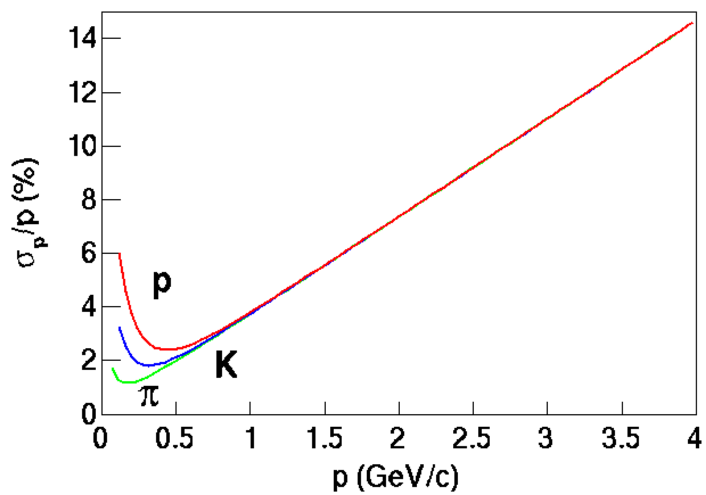
momentum p
pathlength L
time-of-flight t

$m = p/\gamma\beta$ where $\beta = L/ct$

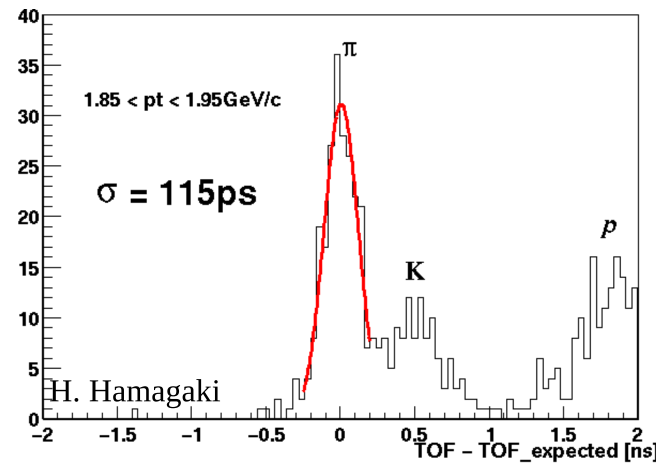
$|m_{meas}^2 - m_{cent}^2| < 2\sigma_{m2}^2$

$$s_{m^2}^2 = \frac{s_p^2}{p^2}\left(4m^4\right) + \frac{s_t^2 c^2}{L^2}\left(4p^2\left(m^2 + p^2\right)\right)$$

Momentum resolution

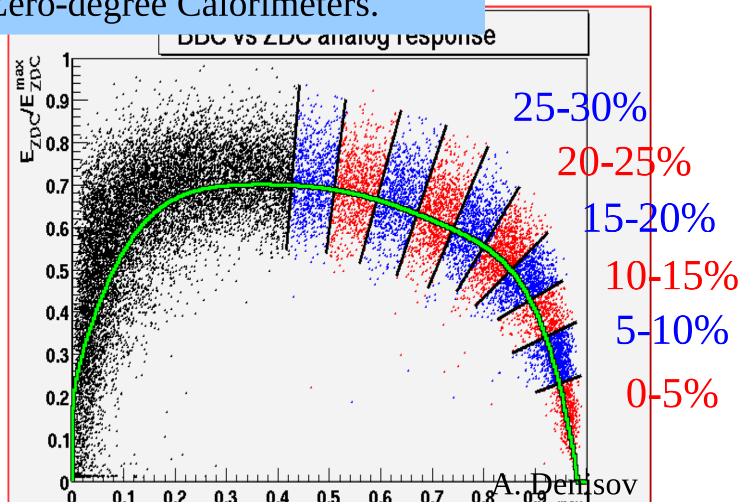


Time-of-Flight resolution

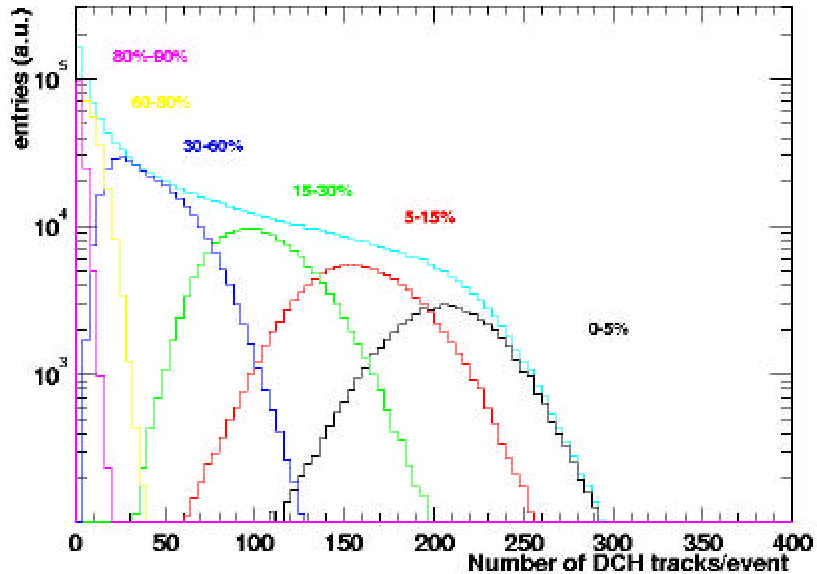


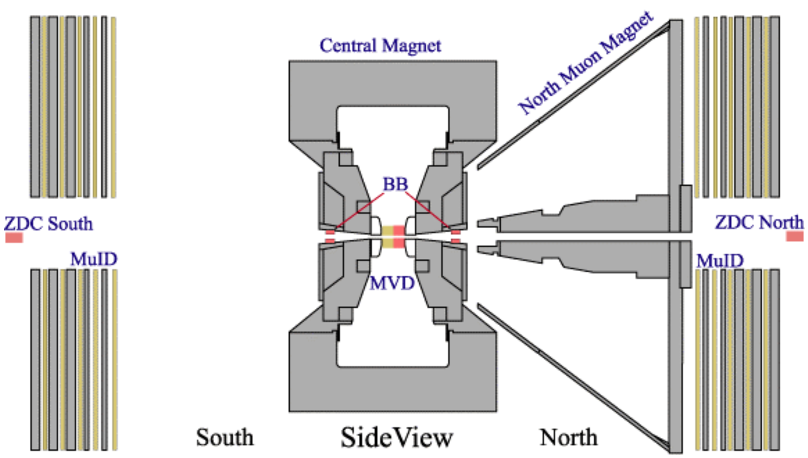
Event centrality: how “head-on” is the collision?

The fraction of energy deposited in the Zero-degree Calorimeters.



The fraction of counts in the Beam-beam Counters.

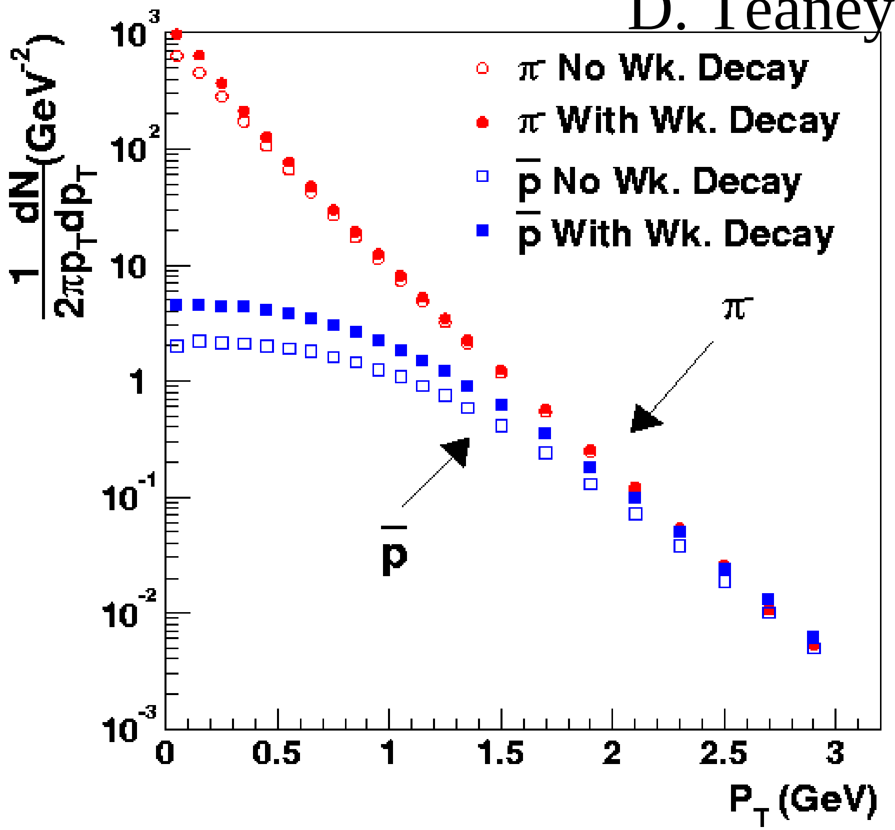




Centrality	Collisions	Participants
0-5%	945 ± **15%**	347 ± **15%**
5-15%	673 ± **15%**	271 ± **15%**
15-30%	383 ± **15%**	178 ± **15%**
30-60%	123 ± **15%**	76 ± **15%**
60-80%	19 ± **60%**	19 ± **60%**
80-92%	3.7 ± **60%**	5 ± **60%**

H2H Model
The Effect of Weak Decays

D. Teaney



$K^0_s \rightarrow \pi^+ + \pi^-$

$\overline{\Lambda} \rightarrow \pi^+ + \overline{p}$

$\Lambda \rightarrow \pi^- + p$

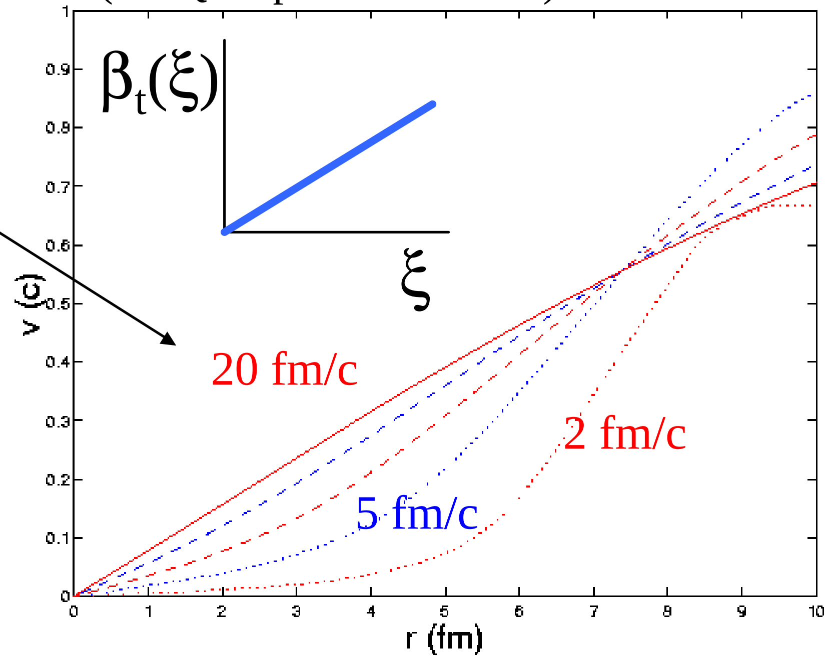
The measured contribution to nucleon spectra from such "real" background is forthcoming.

From Hydrodynamics: Radial Flow Velocity Profiles

Velocity profile
at $\tau \sim 20$ fm/c
"freeze-out"
hypersurface

At each "snapshot"
in time during the
expansion, there
is a distribution
of velocities
that vary with the
radial position r

(No QGP phase transition)



Plot courtesy of P. Kolb

Effective Temperature and Linear Fit

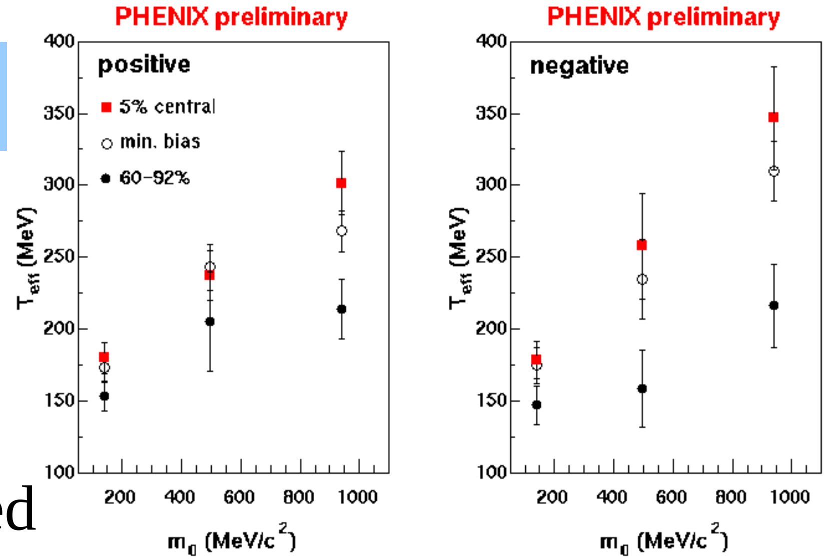
$$\mathbf{T_{eff} = T_{fo} + m_0 \langle b_t \rangle^2}$$

5% central

$T_{fo} \sim 132 - 166$ MeV

$\langle \beta_t \rangle \sim 0.4 - 0.6$

Systematic errors included

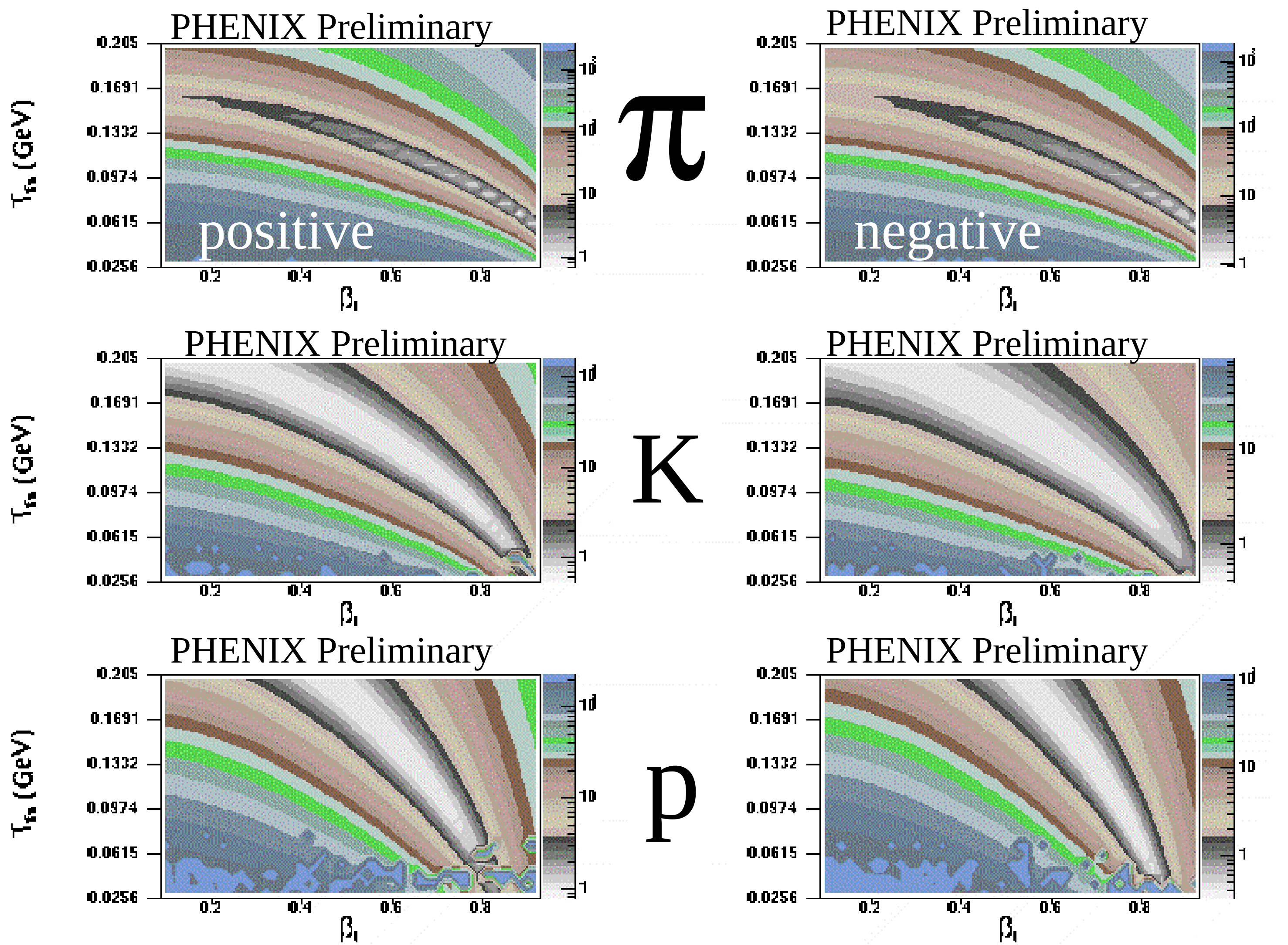


Compared to hydrodynamics-based parameterization:

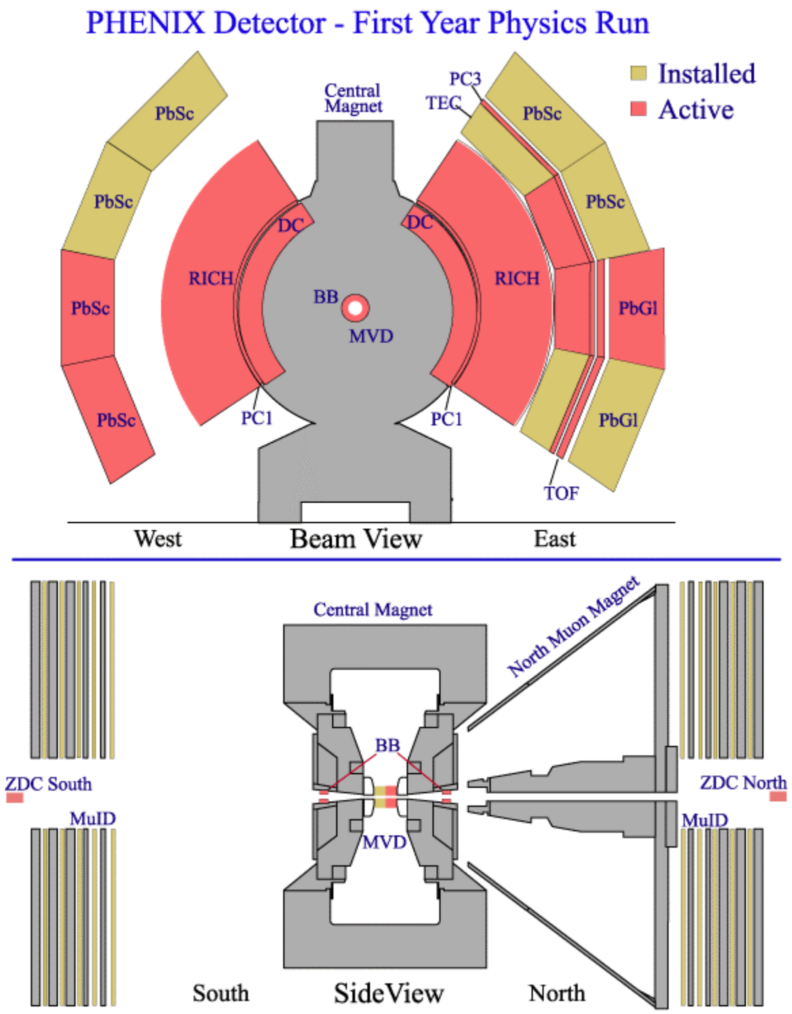
T_{fo} within 30% and $\langle \beta_t \rangle$ within 6%

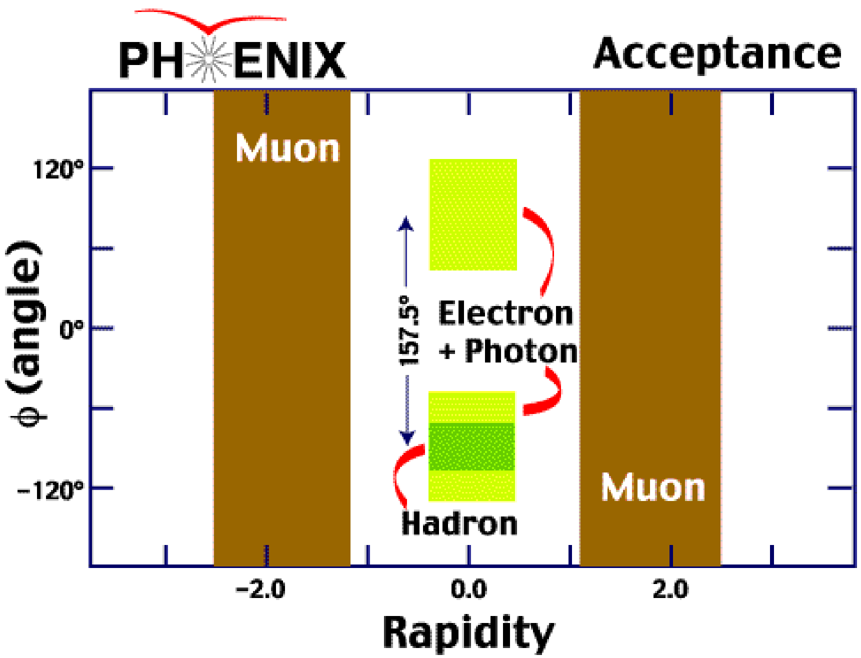
Centrality	**Positive**		**Negative**	
	$\mathbf{T_{fo}}$	$\langle b_t \rangle$	$\mathbf{T_{fo}}$	$\langle b_t \rangle$
min. bias	**161±12**	**0.39±0.07**	**151±15**	**0.41±0.07**
5%	**159±13**	**0.39±0.07**	**149±17**	**0.46±0.1**
60-92%	**143±12**	**0.28±0.1**	**134±16**	**0.28±0.1**

$\chi^2\,(T_{fo},\beta_t)$ Contours



The PHENIX Detector





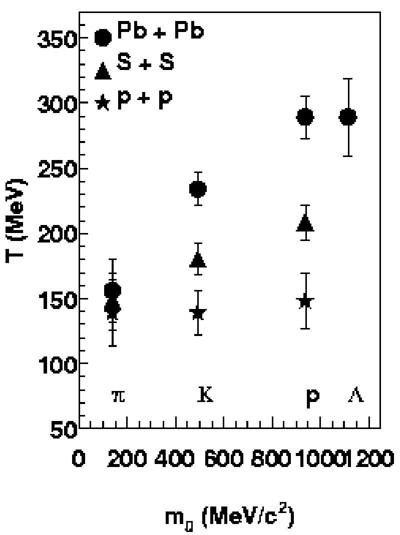
$-0.35 < \eta < 0.35$

4.5M min. bias events

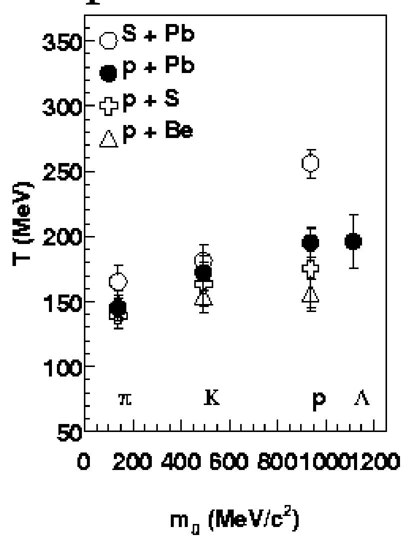
Relevant CERN SPS Observables

T_{eff} depends on $m_0 \rightarrow$ radial flow

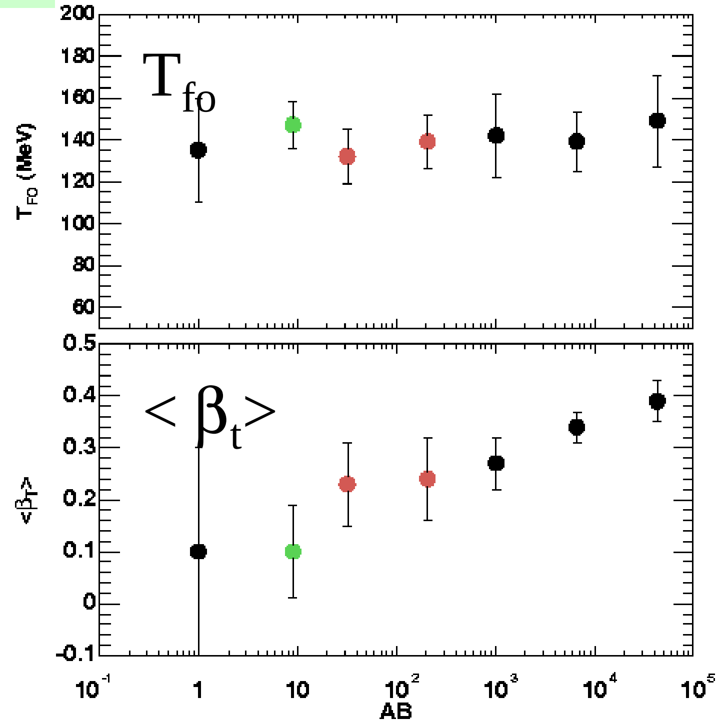
A + A



p + A



$T_{eff} = T_{fo} + m<\beta_t>^2$



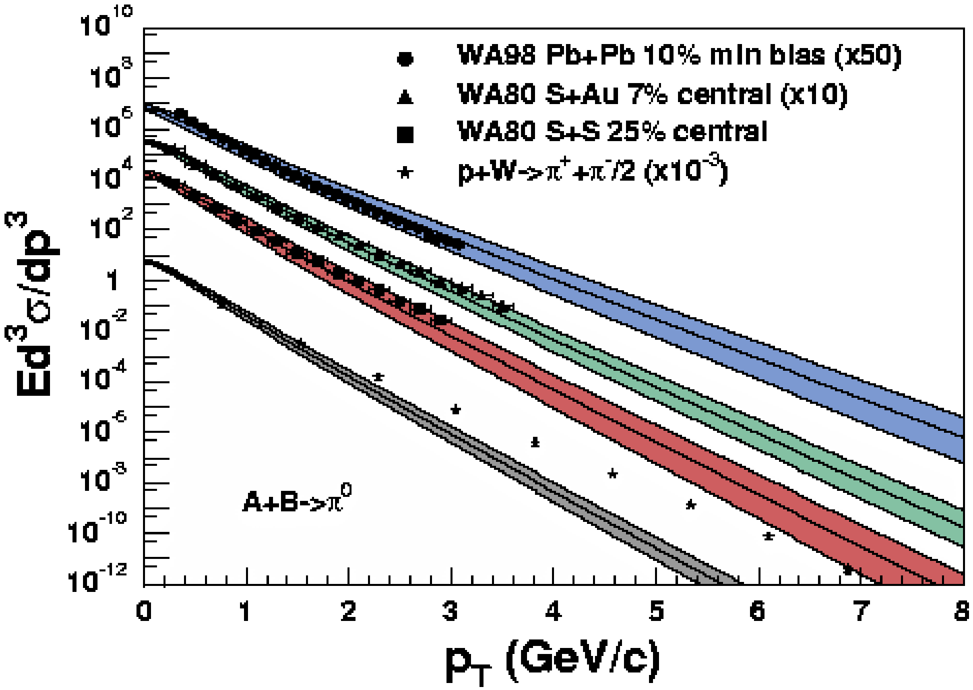
Bjorken's formula:
initial energy density

$<\varepsilon_0> \sim 1/\pi R^2 \tau_0 \, dE_t/dy$

$<\varepsilon_0> \sim 3$ GeV/fm^3 (NA49)

System Size = $A_1 A_2$

CERN SPS
Hydrodynamics-Based Parameterization



The spectra are well described using hydrodynamic assumptions.

CERN Pb-Pb NA49:
T ~ 132 - 108 MeV ~ 120 MeV
β_t ~ 0.43 - 0.67 ~ 0.55